Algorithm for calculating the technological parameters of the process of extrusion of rods from powder compositions based on iron

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Algorithm for calculating the technological parameters of the process of extrusion of rods from powder compositions based on iron

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Abstract. An algorithm is proposed for calculating the technological parameters of the process of extruding rods from iron-based powder compositions, which makes it possible to predict the density of the rods depending on the initial porosity of the briquette, the drawing ratio, the taper angle of the matrix, and determining the extrusion pressure. Criteria are selected for the selection of conditions allowing, after extrusion, to obtain a bar suitable for subsequent thermomechanical processing. The obtained data is supposed to be used for technological calculations of the processes for the production of engineering parts by powder metallurgy methods.

1. Introduction

Parts for general engineering purposes occupy a predominant place in powder metallurgy. So in recent years, up to 80% or more of the powder parts market in Europe was accounted for by engineering products based on iron [1,2], "figure 1". Similar indicators in the leading countries-producers of powders and products from them in North America (USA, Canada) and in Asia (China, Japan, South Korea, India).

One of the main consumers of iron powders and steels, as well as products from them, is the automotive industry of developed countries in Europe, America and Asia (for automotive parts, including engine parts, transmissions, valves, pumps, bushings, etc. in total consumption iron powder products and compositions based on them account for up to 70% or more). A more detailed list of automotive parts manufactured by powder metallurgy methods can be seen, for example, in the booklet Metal Powder Industries Federation, which unites manufacturers of powders, products from them, equipment for the production of powders and products mainly from North America, as well as Europe and Asia (https://www.mpif.org/MarketPM/PM_AutoCat_Parts_Listing.pdf).

An important technological technique for increasing the density and strength of powder parts, improving their microstructure, including iron powder and compositions based on it, is the rational alloying of the charge. Moreover, when developing the technological parameters of the process of pressing powder billets, it is important to ensure the possibility of their subsequent thermomechanical processing in the green state, which can significantly reduce production costs.

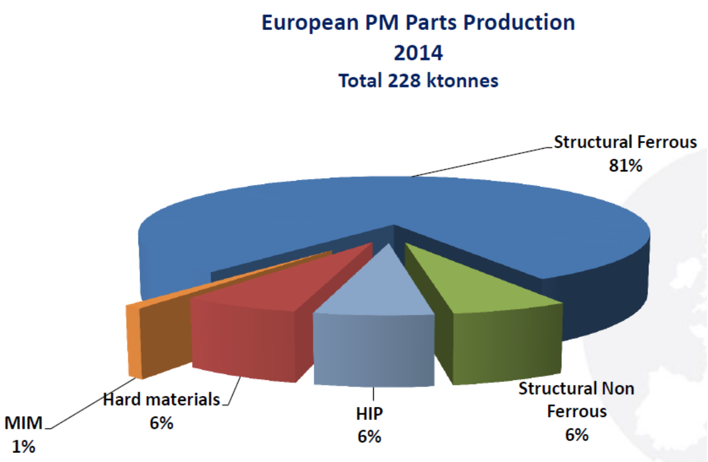

Figure 1. The market structure of powder parts in Europe in 2014.

This fully applies to the extrusion process, which is one of the main technological processes of powder metallurgy. In particular, cold extrusion expands the capabilities of powder metallurgy. So, in [3], the rationale for cold extrusion is given in terms of cost reduction, productivity and ductility, environmental friendliness of the technology. Cold stamping and extrusion have several advantages: minimum waste, high dimensional accuracy, reduction or complete elimination of mechanical processing, better mechanical properties than the original, due to the favorable grain structure [4].

2. Determination of the yield strength of the base material and the minimum required density of the workpiece for extrusion

When choosing the technological parameters of the process of extruding billets from non-compact raw materials, a number of problems are solved, including determining the extrusion pressure and the value of residual porosity depending on the extrusion ratio, taper angle of the matrix, and initial bore porosity. It should be borne in mind that the lower the briquette pressing pressure before extrusion (and, accordingly, its density), the lower the load on the stamping tool and the energy consumption for pressing. On the other hand, the density of the briquette before extrusion should be such that the rod e is destroyed. Therefore, it is necessary to determine the minimum density of the workpiece, allowing to obtain after extrusion a bar suitable for subsequent machining. At this stage, we confine ourselves to the assumption that the content of dopants in the powder composite is sufficiently low (not more than 5–7%).

A schematic diagram of the selection of rational technological parameters of the cold extrusion process of powder compositions is presented below, figure 2.

At the first stage, mathematical modeling and experimental studies of the processes of compaction and extrusion of the base material of a powder composite are carried out (without alloying additives).

The extrusion pressure and residual porosity are calculated using formulas (1) - (3).

Densification stage before extrusion:

$$p_1^+ / \sqrt{3}\tau_s = (2/3)\left[1 - k\cdot\theta^{2/3} - ln(\theta/\eta)\right] + p_{mp} \tag{1}$$

Where p^+ - is the upper estimate of the pressing pressure, τ_s - is the yield strength of the base material (solid phase) during shear, k,η - are the coefficients in the expressions relating the yield strengths for compression and shear with porosity, p_{fr} - are the pressure loss to overcome external friction, θ - is the porosity.

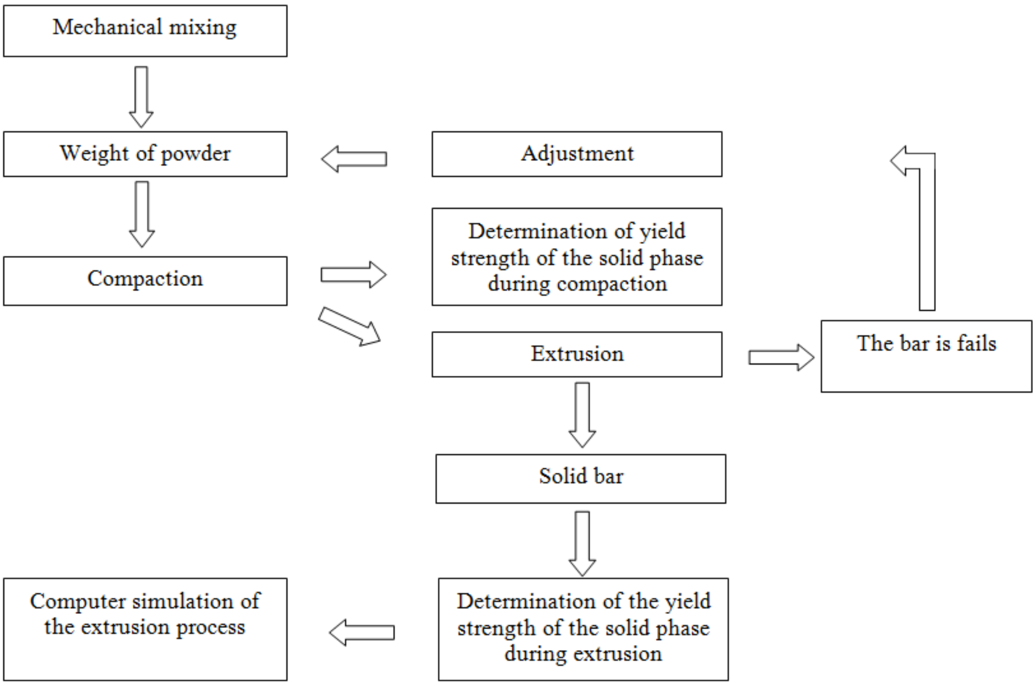

Figure 2. Scheme for the selection of technological parameters.

Extrusion Stage:

$$p_2^+ / \sqrt{3}\tau_s = 8/\left(9tg^2\alpha\right)\cdot\left(1-k\cdot\theta^{2/3}\right)\left[\left(1+0{,}75\cdot tg^2\alpha\right)^{\frac{3}{2}}-1\right]ln\,\mu+$$
$$+\left(4/3\sqrt{3}\right)\cdot\left(1-k\cdot\theta^{2/3}\right)tg\alpha' + \left(f/\sqrt{3}\right)\cdot ln\,\mu\left(ctg\alpha' + tg\alpha'\right)+p_{mp} \tag{2}$$

where $p_{fr} = (2/3)\left[1-k\cdot\theta^{2/3}-ln(\theta/\eta)\right]\cdot\left(\xi f L_1/R_0\right)$ - pressure loss to overcome external friction according to G.M. Zhdanovich [5], $k \geq 1$ and $\eta = [0{,}48 \div 1{,}0]$ according to work [6], $\alpha' = arctg\left[(R_0-R_1)tg\alpha/\left((R_0-R_1)+(L_1+L_2)tg\alpha\right)\right]$.

In accordance with the accepted approach of the values $p_1^+/\sqrt{3}\tau_s$ and $p_2^+/\sqrt{3}\tau_s$ the smallest is selected from the values:

$$p^+/\sqrt{3}\tau_s = \min_i\left(p_i^+/\sqrt{3}\tau_s\right), \quad i=1{,}2 \tag{3}$$

In order to determine the extrusion pressure of a real material, it is necessary to know the yield strength of the solid phase, which has different values for the compacting stage and extrusion stage. Therefore, it is necessary to obtain compaction curves during densification stage and the "pressure – relative density" curves depending on the extrusion ratio at the extrusion stage. For this, experimental studies of the compaction and extrusion processes for the base material of the powder composite are carried out. Also, at this stage of research, the minimum density of the workpiece is determined, which allows, after extrusion, to obtain a bar suitable for subsequent thermomechanical processing. This stage corresponds to the position "adjustment" (figure 2). In this case, this means an increase in the initial density of the preform before extrusion to a value that ensures the suitability of the bar for further processing.

3. Prediction of the minimum required density of the composite preform based on the shear resistance.

At the next stage, tests on uniaxial and diametral compression in the green state on specimens from the base material, as well as the proposed compositions are carried out. The following formulas are used.

In tests for diametral compression test, the horizontal stress in the center of the disk σ_d at which a specimen fails [7, 8]:

$$\sigma_d = 2P / \pi Dt \tag{4}$$

Where σ_d is the stress at which a crack arises during diametral compression, P is the force at the moment the fracture of the sample, D is the diameter of the sample, and t is the thickness of the sample.

With uniaxial compression, the stress at which a crack occurs in the sample is determined by the formula:

$$\sigma_c = 4P / \pi D^2 \tag{5}$$

where σ_c – stress at which a specimen fails during uniaxial compression

The results of uniaxial and diametral compression tests were used to determine the parameters in the Mohr-Coulomb strength criterion [8]:

$$\tau = p_\sigma \cdot tg\beta + d \tag{6}$$

where $p_\sigma = -\sigma$, σ,τ - the mean stress and deviatoric stress and quantities p_σ,τ are determined by the formulas [8]:

$p_\sigma = \sigma_c / 3$, $\tau = \sigma_c$ with uniaxial compression;

$p_\sigma = 2\sigma_d / 3$, $\tau = \sqrt{13} \cdot \sigma_d$ with diametral compression

The parameter values $tg\beta, d$ are determined by the formulas [9]:

$$d = \frac{\sigma_c \cdot \sigma_d \cdot \left(\sqrt{13} - 2\right)}{\sigma_c - 2\sigma_d}, \; tg\beta = \frac{3\sigma_c - d}{\sigma_c} \tag{7}$$

where β - internal friction angle (cohesion angle in $\sigma - \tau$ plane), d - cohesion.

As a result, the minimum shear resistance is determined d for the base material, which makes it possible to obtain a bar suitable for subsequent thermomechanical processing.

Further, the obtained value d is used in the analysis of the test results of the newly considered (proposed) powder compositions. By the dependences of the value d on the relative density ρ_{rel} relative density (density of the porous material, referred to the density of the compact), it is possible to determine the minimum value ρ_{rel} that the workpiece from the newly studied composition must have so that after extrusion, the bar does not collapse.

4. Prediction of areas of occurrence of defects and possible destruction during extrusion.

The problem of calculating the extrusion pressure and residual porosity can be solved using dependencies (1) - (3). To determine the minimum porosity of the briquette that provides a bar suitable for further processing, the results of experimental studies and data on the shear resistance d obtained for the base material should be used.

Due to the small amount of alloying additives, the indicated dependences for the “pure” powder and compositions based on it with a low content of alloying components will slightly differ from each other.

The calculated formulas (1) - (3) make it possible to determine the real average residual porosity and extrusion pressure for a particular material, for a given drawing coefficient and taper angle of the matrix. According to these data, as well as knowing the initial porosity of the workpiece and the dependences “extrusion force - tool movement”, it is possible to carry out mathematical modeling of the extrusion process in one of the software systems (ABAQUS, ANSYS, DEFORM, etc.). As a result, we obtain the distribution of residual porosity and the stress-strain state in various sections of the bar.

After the practical implementation of the extrusion process according to the described algorithm, the necessary physical, mechanical and other properties of the bars are determined and the obtained values are compared with the requirements of National Standart, customer conditions, etc. If necessary, the conditions for the implementation of the process are adjusted (change in the coefficient of extraction, the addition of plasticizer, etc.).

The indicated approach can also be applied for backward extrusion processes, ECAP (equal-channel angular pressing).

5. Conclusions

Methodological recommendations on the selection of rational technological parameters of the process of extruding rods from iron-based powder compositions have been developed, which make it possible to determine the minimum initial density of the powder composition, which makes it possible to obtain a rod suitable for subsequent thermomechanical processing after extrusion.

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